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MET O 11 TECHNICAL NOTE NO. 104

Rainfall forecasts from the 10-level model

by

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Appendix: The operational numerical forecasting system.

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NOTE: This paper has not been published. Permission to quote from it should be obtained from the Assistant Director of the above Meteorological Office Branch.

Preface

Although this Note is unlikely to retain its topicality for very long, it does represent the accumulated experience of six years close association with the rainfall forecasts of the 10-level model. As such it may have some immediate value.

The author is grateful to his colleagues in Met O 11 and Met O 2 for their helpful comments on the original draft.

January 1978

1. Relevant features of the numerical model

1.1 Resolution

The horizontal grid-length of the rectangle version of the 10-level model is 100 km. The vertical separation between successive levels is 100 mb, which is about 3000 ft near the ground and about 5000 ft in mid-troposphere. The forecast time-step is 12 mins. (See Figures 1 and 2.)

So the computed value of each meteorological variable at any grid-point in the model represents the mean value of that variable over a volume of the atmosphere $\approx$ 100 km x 100 km x 1 km for a period of 12 minutes.

1.2 Model variables

The basic variables of the model are:

a. Heights of the 10 pressure levels from 1000 mb to 100 mb. From these are derived the partial thicknesses of 9 layers, representing the mean temperature of the layers, centred on 950, 850, ... 250, 150 mb.

b. Horizontal wind components (u,v) at each level, from which are derived the vertical wind components using the principle of conservation of mass represented by the Equation of Continuity.

c. Relative humidity is the humidity parameter which is supplied to the model as data and is analysed. It is converted to Humidity Mixing Ratio for the forecasting equations. Mean values of the HMR are computed for the mid points of the bottom 7 layers only (950, 850 .... 350 mb).

There is no moisture at all in the top two layers of the model. It should be noted that 'clouds' are not explicitly modelled, i.e. 'cloud-water mixing ratio' is not one of the model's variables. When the HMR exceeds the saturation value at any grid-point, the excess water vapour is immediately converted to rain (or snow) and falls out. No part of it is held in the model's 'atmosphere' as cloud-water.

1.3 Topography

The effects of topographic height are included in the model in a limited way, but the resulting effect on the rainfall distribution is negligible. Even the 'raw' topographic heights used in the model are average heights over 100 Km squares, and since these values are themselves smoothed, the resulting topography, except over major mountain ranges, is very flat and featureless. Another result of the smoothing process is to spread the effects of the topography away from actual mountains and, as in the case of the British Isles, even out over the sea.

The distribution of land and sea has a marked effect on the initiation of convective rainfall in the model, through the process of insolation and the transfer of heat and moisture at the surface. Showers are forecast over the sea much more readily than over the land.

1.4 Precipitation processes

Precipitation is produced in two ways in the model, conventionally referred to as 'dynamic rainfall' and 'convective rainfall'. A record is kept of the instantaneous rate and the accumulated amount of both these quantities at each surface grid-point.

The total rainfall forecast at any grid-point is the sum of the dynamic rain and the convective rain. The two processes are not mutually exclusive and in general the rainfall at a particular grid-point is made up of contributions from both the dynamic and the convective processes.

'Dynamic rain' is formed when the horizontal and vertical wind fields forecast by the model lead to the occurrence of supersaturation at a grid-point at some level.

'Convective rain' is derived from the process of examining the forecast vertical temperature structure at a grid-point. This is done at each time-step. It is a complex process, analogous in concept to the 'parcel method' of assessing convective activity on a Tɸgram and may necessitate the 'convective adjustment' of the vertical temperature and humidity structure.

In simple terms, if supersaturation occurs as the result of either of these processes, the excess moisture is condensed and then dropped vertically down through the lower layers. Part of the rain may be evaporated if it falls through unsaturated layers, but any that reaches the bottom level of the model is recorded as precipitation, and is totally removed from the model atmosphere. Although dynamical rain is always initiated at some saturated level, it is not uncommon for convective rainfall to be forecast from an unsaturated column of air when an unstable temperature profile is accompanied by ascending vertical motion.

1.5 Types of precipitation

Although the appropriate Latent Heats (with respect to water or ice) are used in the equations describing the physical processes in the model, 'rain' and 'snow' are not treated as two separate entities. The excess moisture which reaches the ground is recorded as 'precipitation' and it is then a matter of interpretation whether this is to be called rain or snow. Observational data, relating 1000-850 mb thickness with the occurrence of rain or snow at the ground, is currently used to interpret the numerical output in this respect.

Also there is no explicit definition of drizzle, or hail in the numerical model, nor has any satisfactory scheme yet been devised for interpreting the output in terms of these phenomena.

2. Precipitation systems which can be described by the model

The resolution of the model, both horizontally, vertically and in time, largely determines which atmospheric precipitation systems can be described and forecast.

Clearly it is not possible to describe explicitly any system such as an individual shower, or even a thunderstorm, which is a lot smaller in size than the horizontal grid-length of the model. Not only is its spatial resolution much too coarse, but for most convective phenomena the forecast time-step does not allow adequate temporal resolution either. However, as is assumed in normal forecasting practice, the average characteristics of a field of convective clouds and showers can be related to the general temperature structure and instability of the atmosphere. The latter can be modelled, within the limits imposed by the vertical resolution of the model, and it is observed that the distribution of the forecast 'convective rainfall' does provide a useful, practical indication of the occurrence of showers. There is no doubt though that the numerical forecasts of convective activity still leave much to be desired and they should always be interpreted as giving general, rather than particular, advice.

Precipitation from shallow layer clouds is another type which cannot be handled properly, this time because of the coarse vertical resolution of the model. An important example is drizzle (or its frozen variants in winter) which falls from a layer of low stratus cloud. Since the model can only describe the lowest part of the atmosphere by means of average thickness and humidity values located at 950 mb ($\approx$ 1700 ft) and 850 mb ($\approx$ 4700 ft) it is unable to describe the details of such shallow cloud systems with any accuracy.

The systems which the model can handle well, and which it was originally designed to investigate, are those which have dimensions greater than 2 or 3 grid-lengths in both the horizontal and the vertical. This includes any atmospheric system characterised by deep and extensive cloud layers, such as fronts and all large-scale cyclonic features. It must be recognised however that recent observational research has shown that many of the most significant areas of precipitation formation within these large-scale systems have a dimension of 50-100 km. This is a sub-grid scale size, and meso-scale variations of this nature embedded within the overall pattern will necessarily be very smoothed by the model.

3. Displaying precipitation on numerical forecast charts

3.1 General

The rainfall depicted at grid-points on a forecast chart for a particular time is the (total) rate of rainfall during a single time-step of the forecast integration (see Figure 3). It may be assumed that this is representative of the rainfall rates occurring within a few time-steps of that particular time in most situations. On some occasions, however, convective rainfall rates at individual grid-points have been observed to vary quite dramatically over a few time-steps.

Since the total rainfall rate at each grid-point is often partly dynamic and partly convective, it is necessary for the computer routine which displays the rainfall distribution to be programmed in such a way that appropriate symbols are chosen for the most acceptable interpretation of the numerical results.

3.2 Character of the precipitation - Frontal or showery

The basis of the current scheme of presentation is to distinguish as clearly as possible between areas of 'frontal rainfall' and areas of 'showers'. As a result of experience of the model's performance and the observed balance between forecast dynamic and convective rainfall rates it is done in the following way:

A circular symbol (O), representing frontal rain, is plotted at any grid-point where some dynamic rain is forecast, even though it may be much less than the convective rain forecast for that point. If no dynamic rain is forecast, then a symbol (V), somewhat reminiscent of the synoptic shower symbol, is used to indicate the purely convective rain at the grid-point.

3.3 Intensity of precipitation

In general, the size of the symbol reflects the intensity of the precipitation. Larger symbols indicate heavier rain. For frontal rain there are four categories - 'very slight, slight, moderate, heavy'. For showers, the categories are reduced to three. Also in the latter case the intensity is given by the rate of precipitation underneath the convective cloud, and not to the average rate over the whole grid-square. This parameter is predicted by the deep-convection scheme in the model.

3.4 Type of precipitation - rain or snow

It has been found preferable to indicate the distinction between rain and snow falling at the ground by two (dashed) probability lines, rather than by using different symbols. The two lines are in fact, thickness lines (of the 1000–850 mb layer) but they are labelled "20%*" and "80%*".

The use of these lines was based on work by Lowndes et al (Met: Mag: Dec 1974) and strictly apply only to the limited area of Wales and SW England from which the experimental data were taken. However the lines are drawn over the whole oceanic and continental area of the forecast chart, but away from the British Isles their usefulness has never been checked and in such regions they should be used with caution.

The probability values give the chance of snow occurring at sea level. It is left to forecasters to interpret this in terms of its likelihood over high ground or to forecast important details like snow turning to rain (or vice versa). In broad terms:

To the south of the 20% line there is little likelihood of the forecast precipitation being in the form of snow;

To the north of the 80% line it is almost certain to be snow;

Between the two lines, the model indicates that snow is a definite possibility but it is left to the forecaster to assess the situation and supply the detailed forecast.

4. Statistical properties of the precipitation forecasts

This section describes some general properties of the rainfall forecasts which are readily observable in monthly or seasonal statistics. The results are derived from 6-hour or 12-hour rainfall accumulations, rather than from instantaneous rates. Individual forecast runs do not all follow the general pattern.

4.1 Variations of rainfall with time during a forecast run

There is no rainfall in the model at the initial time. It starts from the initial fields of winds, thicknesses and moisture, and no precipitation can actually be recorded until the end of the first time-step. In the early hours of a forecast run therefore, the forecast rainfall is very seriously deficient both in quantity and in distribution.

The initial fields of vertical motion and humidity are always too smooth, and not mutually consistent since they are derived from independent analyses. It takes some hours before the model develops realistic physical gradients which lead to useful rainfall forecasts. The accumulations for the first 6 hours are only about half what would have been forecast had that particular period occurred later in the forecast run. Also, since the convective processes in the model produce rainfall much quicker than the dynamic processes, the first 6 hours rainfall is strongly dominated by the convective contribution.

Usually the model is fully organised and running coherently from (T+6) or (T+9) onwards. There is a slight tendency for the forecast rainfall accumulations, especially of convective rain, to continue increasing with time. The effect is rarely observable on individual runs but in general the (24-36) hour accumulations are some 7% larger than the (12-24) hour accumulations for the same period.

4.2 Seasonal variations in forecast performance

Over the British Isles and NW Europe, where there are sufficient data to make comparisons between forecast and actual rainfall totals, the overall ratio of forecast/actual rainfall shows a regular seasonal variation.

The ratio is high in winter (85%) and low in summer (45%). So, regardless of whether the forecast rain areas are in the right place at the right time the model produces much more like the right quantity of rainfall in winter than it does in summer. This reflects the prevalence of oceanic cyclonic systems over the area in winter, which are within the scope of the model to analyse and forecast. And the importance of convective processes in summer, which are rather poorly described by model.

4.3 Consistency of the forecasts from successive runs

If forecasts of 12 hour accumulations for an area (about 4 x 4 grid-points) are considered, then it is found that about 2/3 of the forecasts at (24-36) hours from one run are supported in general terms by the corresponding forecasts at (12-24) hours from the next run. Only on some 5% of occasions are successive forecasts for the given area and time widely at variance.

These figures appear to be reasonably good but they disguise the fact that at least half the forecasts are for dry weather and are comparatively trivial. The important, and difficult, rainfall forecasts invariably involve the occurrence of moderate or heavy rain. These are comparatively rare events but in fact they figure rather prominently in the 5% of occasions mentioned above. Only about one third of all forecasts of significant areal rainfall are supported by a similar forecast at a later, or earlier, time. This lack of consistency on those occasions when forecasters are particularly looking for useful advice has always been a discouraging feature of the numerical rainfall forecasts. It has markely limited the confidence which forecasters have so far developed as to the reliability and usefulness of the numerical products.

In general there is no simple rule that forecasts 'nearer the time' are consistently more reliable than those from earlier runs. There is a random effect at work, which could well derive from the precise location and representivity of the scattered oceanic data used in each forecast run.

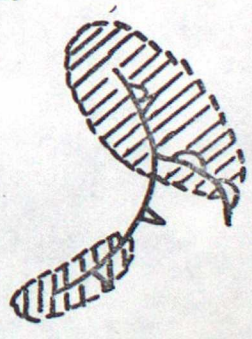
5. Some synoptic characteristics of the rainfall and pressure forecasts

This section describes some common characteristics of the distribution of rainfall and pressure patterns seen on numerical forecast charts. Like all aspects of synoptic meteorology there is a quasi-infinite set of possible situations. The following generalisations, though subjective, are thought to be widely acceptable by those who have worked with the numerical output.

5.1 Representation of rain areas

The discontinuous, grid-point representation of rainfall (or any other variable) necessarily results in maximum values being truncated, steep gradients being blurred, and forecast rain bands generally appearing to be a little wider than they should be.

The typical rainfall pattern associated with a well-developed frontal depression frequently shows considerable rain associated with the warm front and occlusion. There is often a break in the rain area associated with the cold front.



5.2 The movement of synoptic scale troughs - too slow

It is an inherent drawback of all numerical models based on a grid-point representation that they cannot compute derivatives ($\frac{\partial h}{\partial x}$ etc) precisely but have to use finite difference approximations. These approximations lead to an underestimation of the movement of synoptic scale features such as fronts and rain

troughs. With the 10-level model the error in the predicted location of rainbelts is on average about 1 grid-length per 12 hours of forecast time.

5.3 Rain areas and surface pressure patterns

It may be surprising for forecasters, who use surface pressure charts as a fundamental tool of their trade, to find that surface pressure is not one of the basic variables of the 10-level model (though the closely related '1000 mb height' is). Indeed, surface pressure patterns are amongst the most difficult fields for the model to handle well.

The rectangle does not usually maintain strong local pressure gradients very well. It often loses them quite quickly during a forecast run, even though the initial field may have been realistic. Circular-shaped depressions frequently degenerate during the forecast into elongated and flabby troughs. Small-sized, deep secondary depressions(which in practice may be responsible for some of the most significant rainfall events) are very rarely predicted at all.

It is interesting to note, though, that the degeneration of the surface pressure pattern during a forecast run does not necessarily imply that all dynamical processes are correspondingly weakening at all levels in the model. It is often observed that weak forecast pressure patterns are accompanied by localised areas of organised rainfall. Such forecasts should be interpreted as being reliable indications that significant vertical motion (ascent) is going to occur and an appropriate cyclonic pressure pattern should be inferred in the region of the rain, even though this has not been forecast by the model. The forecast rainfall is often a better indicator than the forecast pressure of the importance and intensity of a cyclonic system.

5.4 The distribution of showers

In general the occurrence of polar maritime showers are (or appear to be) under-forecast over land. They are forecast much more frequently over the sea in all seasons.

With continental thundery situations in summer time there have been some instances of spectacularly successful forecasts, but these have been more than outnumbered by failures (in the proportion of about 2:1 in the important situations).

6. Some synoptic types which are not well forecast by the model

6.1 Small depressions

Many small lows are extremely significant rain producing systems, even though they are small in area. Frontal wave depressions, and polar lows, are examples.

Such lows are frequently not well analysed or forecast by the numerical forecast system. They mostly originate over the sea, so that inadequate data may be a frequent cause of trouble. Also their size - maybe no more than 1-2 gridlengths - is a constant handicap to a successful forecast. The central pressures of all small depressions, especially if they are active and deepening, are rarely forecast to be nearly as low as they should be.

6.2 Complex patterns with small-scale features

The model is more successful at dealing with one clear-cut, medium-sized depression (or anticyclone) than it is with a complex pattern consisting of a number of smaller scale features. Thus, for example a series of small frontal waves, or a succession of troughs around a large cyclonic vortex, or a vague and indeterminate pattern of minor lows and highs are not likely to be correctly forecast in detail. The model will normally try to develop one of the small systems at the expense of the others, but it is not

necessarily reliable at choosing the right system to develop even if this general mode of evolution is correct. Once again, the ability of the initial data distribution to define the various systems with relative accuracy is probably a crucial factor.

6.3 Very long-wave systems

At the other end of the scale from the small sized systems mentioned so far, the rectangle version of the 10-level model also has difficulty in handling the very largest systems. These are the trough-ridge-trough systems which at times cover the whole area from Eastern America (trough) across the Atlantic (ridge) to W Europe (trough). Systems of such a size cannot be completely contained within the limited area of the rectangle. Their correct prediction therefore depends to a great extent on having good external data provided (from the previous octagon forecast) at the lateral boundary inflow points and on handling these boundary data correctly. In fact the octagon forecast does not always provide the proper indications of increasing meridionality.

Two factors which are relevant are:

i. Since the large-scale pattern necessarily involves some strong meridional flows across the north and south boundaries of the rectangle, errors from these regions will spread in to the area of the British Isles rather quickly, as these boundaries are rather close, and

ii. Since the upwind trough is frequently located right over the western boundary of the rectangle this is a major source of trouble. The correct forecasting of major troughs crossing this boundary has always been a difficult problem which, even with recent improvements, is not yet fully solved. Errors in forecasting the developments in this trough rapidly lead to erroneous broad-scale developments downstream near the British Isles.

6.4 Increasingly meridional flow near the British Isles

This is an example of the sort of situation in which the rectangle may (somewhat uncharacteristically) forecast too much rain over the British Isles.

It is not uncommon for a spell of 'westerly' weather to change to a 'southwesterly' type when the controlling Atlantic jet-stream develops a buckled shape. A large low slows down as it moves into the Eastern Atlantic and it takes a track more towards the north. At the same time the low level winds over the UK back from W to SW or S, and the Atlantic rainbelts gradually lose their eastward motion as their activity is carried away northwards off our western coasts.

This increasing meridionality in the flow is rarely forecast very convincingly in the rectangle. Consequently the rainbelts are advected too far east with the original zonal flow and forecasts of wet weather are made for areas which actually remain dry.

6.5 Filling depressions

There is a strong correlation in the model between the vertical motion and surface pressure changes (or 1000 mb height changes). A filling depression is characterised by subsidence or very small vertical velocities, and all rainfall within its circulation very soon dies out.

This has given rise to some misleading forecasts; the most significant of them occur on the not infrequent occasions when a low stagnates and fills over the southern parts of the North Sea. Such lows can give rise to very wet conditions over East Anglia and SE England, and the dry conditions normally forecast by the model in such situations are very poor guidance. It has also been observed that the rainfall from old occluded fronts is often under-forecast.

7. Numerical models as a forecasting aid

These notes have been written in order to help forecasters become more aware that numerical forecast products are the end result of a complex, but essentially rational process. For those who have never worked in an environment where numerical forecast systems are developed, or numerical forecasts are produced operationally, the whole process is wrapped in mystery and it is very difficult for them to know how to evaluate the advice given by the numerical products. It is probably a common experience to start by over-valuing the numerical advice and then, after it has let you down a few times in some particular way, to swing to the other extreme and under-value it. Some middle way is cleary desirable.

Numerical forecasts can never give perfect advice. For many reasons it would be idle to pretend they can; thus, to list but a few obvious fundamentals -

a. The initial analyses are bound to be imperfect through lack of data, especially in oceanic areas.

b. The objective procedures which are programmed into the analysis routines and the forecast model cannot be other than incomplete.

c. Conflicting operational requirements will frequently necessitate the forecast to be run under less than optimum conditions, as is currently the case with the rectangle.

But forecasters have never been in the position of having anything remotely resembling perfect advice, and they have always learnt to make very good use of whatever forecasting aids were available to them. It should be realised that numerical forecasts are excellent forecasting aids - but still only "aids". The way to use them is to start by concentrating on the general dynamic evolution which they predict. Subject the resulting forecast to whatever checks are available, especially in respect of the likely data which has been used and then use the numerical product as an essential first

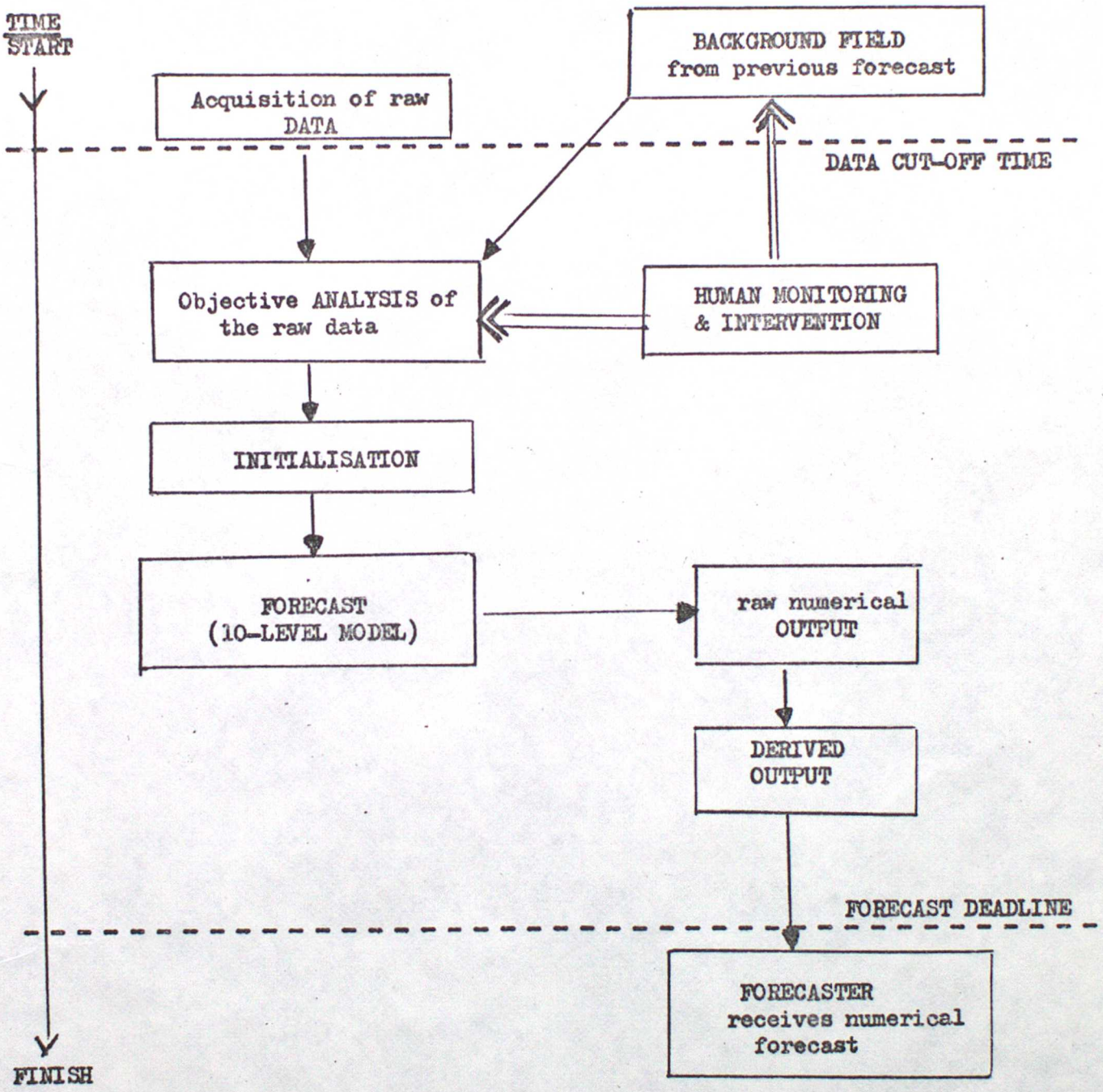
guide to the general pattern of development. It is not profitable to put too much weight on the detailed rainfall forecast for a particular grid-point, unless it be interpreted in a rather general way. But the broad mode of development can normally be accepted, with modifications in detail included by using traditional forecasting techniques.

Appendix

The operational numerical forecasting system

1. Brief outline of the system

The forecasts produced by numerical models are the end product of a long and complex suite of operational computer programs. In order to interpret these forecasts with the fullest possible understanding it is necessary to have some acquaintance with the main features of this system. In broad outline it can be illustrated by the following block diagram, showing the flow of activity from the initial reception of raw data to the final presentation of a computed forecast chart on a forecaster's desk. The outlined procedure is currently repeated twice a day, using data whose nominal time is midnight and midday GMT. A scheme to introduce a six-hourly forecast cycle is under test at the moment for the rectangle. But if it is introduced this more frequent repetition of the forecast schedule will not involve any essential change to the concepts which are described below.


TIME
START
BACKGROUND FIELD
from previous forecast
Acquisition of raw
DATA
DATA CUT-OFF TIME
Objective ANALYSIS of
the raw data
HUMAN MONITORING
& INTERVENTION
INITIALISATION
FORECAST
(10-LEVEL MODEL)
raw numerical
OUTPUT
DERIVED
OUTPUT
FORECAST DEADLINE
FORECASTER
receives numerical
forecast
FINISH

The quality of the output which reaches the forecaster is dependent upon all these steps being correctly designed and functioning properly. It is a very complex system and in practice it is a very difficult matter to assign individual forecast failures to any one precise cause.

2. Acquisition of data

Worldwide data are continually being received at Bracknell on the communications computers in Met O 5. They are immediately passed, within the computer system, to the Synoptic Data Bank in the main COSMOS computer system in Met O 12. Traditional observations at fixed times from surface stations and radiosondes form the backbone of the data; but increasingly, asynchronous data from aircraft, satellites and other remote sounding devices are playing a more important role.

The data items required by the numerical forecast are extracted from the Data Bank and subjected to a number of quality control checks, so as to weed out erroneous observations. At the data cut-off time (currently 0225 and 1425 GMT) the extraction of data has to cease and the remainder of the operational forecast suite is begun. The precise time of the data cut-off has to be arranged under the conflicting requirements of a. being late enough to ensure that as much data as possible is utilised, and b. not being so late that the eventual forecast is delayed beyond its most useful time.

With the current operational schedule, the rectangle forecast is deliberately run as early as it can be and there is always some risk that important ship observations may not be received in time to be included in the forecast run. It is hoped that in the future, forecasters will be presented with an easily digestible display of the data which have been used in a numerical forecast run. They will then be in a position to assess the quality of the forecast in the light of any extra data, of whose existence they are aware through the normal communications channels.

3. Background Fields

Background fields are an essential aid to the objective analysis of the current situation, particularly in regions of sparse data. Over the Atlantic, and especially at upper levels, background fields of contour heights and humidities are very necessary, and it is important that they should be of high quality. In a twelve-hourly forecast cycle, the background fields used on one forecast run are the 12 hour forecasts produced by the previous run. It is an important part of the job of the monitoring and intervention team to ensure that these forecasts provide the best possible 'first guess' for the subsequent analyses.

Unfortunately the constraints of real life dictate that at the crucial hours there is only a limited amount of time available for the intervention team to do all that is ideally desirable. Their efforts are therefore directed primarily towards ensuring a high quality in the octagon forecast, which is the primary operational model, rather than the rectangle. This is one reason why it has been found beneficial for the rectangle analyses to be based on analyses and background fields which have been interpolated from the octagon forecast. This practice also ensures a greater degree of consistency between the octagon and the rectangle forecasts than would otherwise be the case.

4. Human monitoring and intervention

The staffing of the intervention team in CFO was increased in numbers during 1975, and since that time operational intervention procedures have been evolved. Checks are made by the teams to ensure that all erroneous data has been rejected and all good data has been included in the analyses. By using traditional techniques of continuity and incorporating data from satellite cloud pictures for example, they monitor the objective analyses and if necessary, then intervene to incorporate meteorologically realistic fields into the numerical products. But, as with any subjective technique,

there is some variability between the practices adopted by individuals and it is not easy to assess the particular impact of the human intervention on a specific occasion with any certainty. Overall, however, it has been shown to produce beneficial results.

5. Objective analysis

The analysis of the raw humidity data is carried out by an objective procedure, but with the possibility of some amendment through subjective intervention. In this analysis, which is carried out independentaly of the height analysis, the latest observations (which are comparatively sparse over most of the chart) are used as data for adjusting the background field which was produced on the previous forecast run. An important feature is that humidities measured at isolated stations, such as Ocean Weather Ships, are not assumed to be equally representative of nearby conditions in every direction around the station. Instead the effect of the observation is weighted, by making use of the humidity gradient on the background field. So an isolated observation is given most weight in those directions which are parallel to the humidity isopleths, and least weight in directions perpendicular to the isopleths.

6. Initialisation

This is a mathematical process which is mainly concerned with deriving initial wind fields that are consistent with the analysed height fields. The inevitable result of this process is to produce some smoothing and degradation of the analysis, but this is the unfortunate penalty that has to be accepted if the forecast program is to run successfully.

The initialisation process has a minimal impact on the humidity analysis.

7. The forecast program

This is the "10-level model" itself, a version of which was first brought into operational use in August 1972. The fine mesh (rectangle) version of the

model has been used in CFO as an operational forecasting aid for regions in the vicinity of the British Isles since December 1973.

The forecast model, in common with all other parts of the operational system, has undergone continual development since it was first introduced. Many features of the 10-level model are now quite different from the original version, described in Scientific Paper No 32. It is fair to say that for some time now, the model has completed its development phase and is in its operational phase. Frequent alterations to the basic formulation are no longer a commonplace occurrence, although quite radical changes to some aspects of the model are still introduced from time to time.

The 'dynamics' of the model (i.e. the equations which describe the wind flow and the methods used for solving the equations) are fairly well formulated for the purposes of short range forecasting. At forecast times beyond 3 days a loss of energy in predicted wind fields becomes increasingly apparent, but in the rectangle forecasts (up to 36 hours) it is not so, except at the important surface level, as mentioned in para 5.3.

The 'physics' of the model is for various reasons less complete and more open to criticism. The term 'physics' is here used in a restricted sense to describe all the non-dynamical processes in the model, such as precipitation and convection, radiation, the exchange of heat and moisture between the surface and the air - etc. Individually these processes are all very complex and they interact on each other as well so that a lot of computer time is needed to solve the relevant equations. Also, many of the atmospheric properties are not fully understood, especially when expressing them on the scale of the numerical grid.

So a balance continually has to be kept between the desirability of improving the basic formulation of the model against the need to conserve

computation time. It is a balance between the value of a marginally improved forecast that is produced later against that of an acceptable but imperfect product that is issued at a useful time.

8. Derived results from raw numerical output

It is as well to remember that many - or, most - common meteorological parameters are not explicitly forecast by the model. Even surface pressures have to be derived in some way from the results of the numerical computations.

The fact that the numerical precipitation forecasts need to be 'interpreted' before they are plotted on a chart has been described, in para 3.1. Cloudiness is another parameter which is not forecast by the model, but for which useful values can be inferred by making use of the humidity values in the model.

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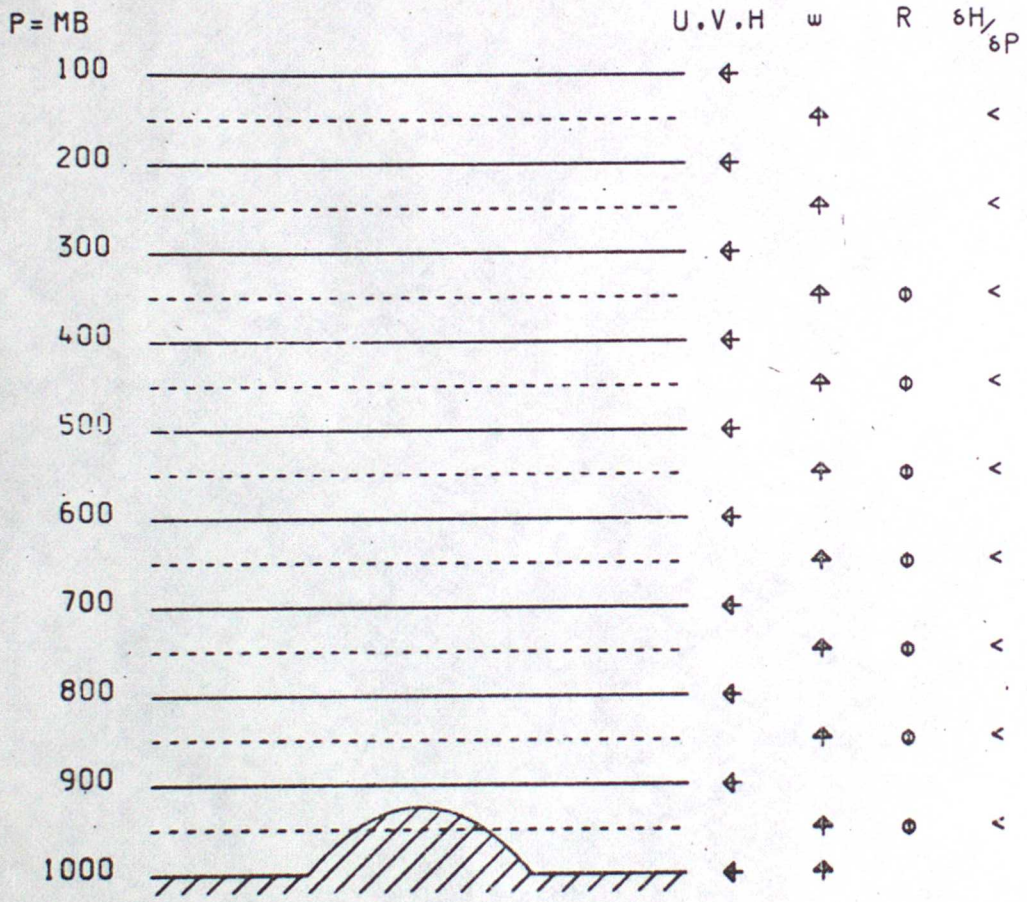
10-LEVEL MODEL
(PRIMITIVE EQUATIONS)



IND VRBLS = X.Y.P.T

TIME-DEP VRBLS = U.V.H.R

ASSOCIATED VRBLS = $w, \delta H/\delta P$

MODEL INCLUDES:

OROGRAPHY
FRICTION
CONVECTION (SHALLOW & DEEP)
LATENT HEAT (INC.ICE PHASE)
SURFACE EXCHANGES (HEAT.MOISTURE)
TIME DEP BOUNDARY CONDITIONS
(FOR RECTANGLE)

	RECTANGLE	OCTAGON
GRID	64X48 PTS	3037 PTS
MESH WIDTH	100 KM	300 KM
TIME INTEGRATION	SPLIT SEMI-IMPLICIT	SPLIT EXPLICIT

FIG 1. The vertical spacing in the 10-level model.

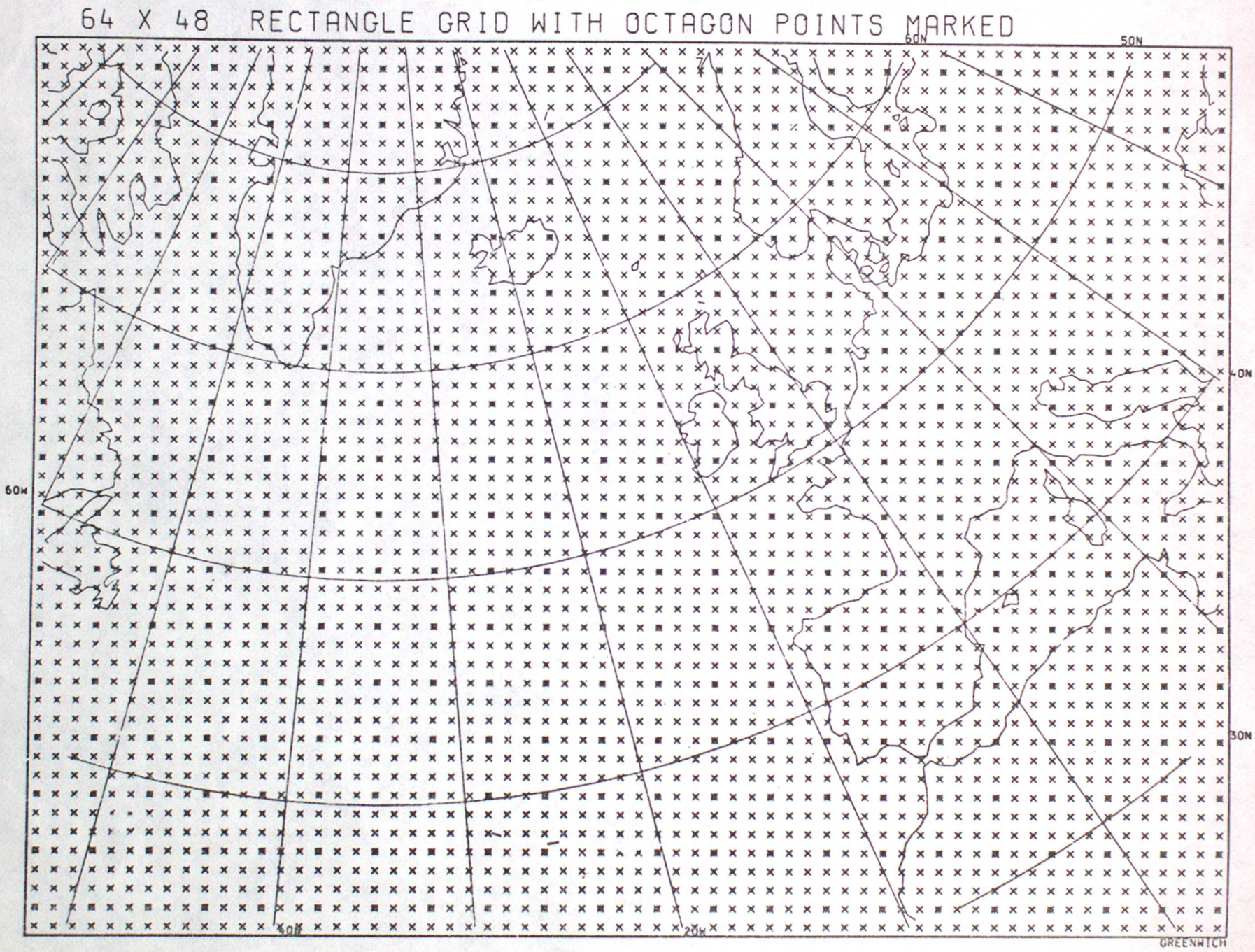


FIG. 2. The horizontal grid used in the rectangle version of the 10-level model.

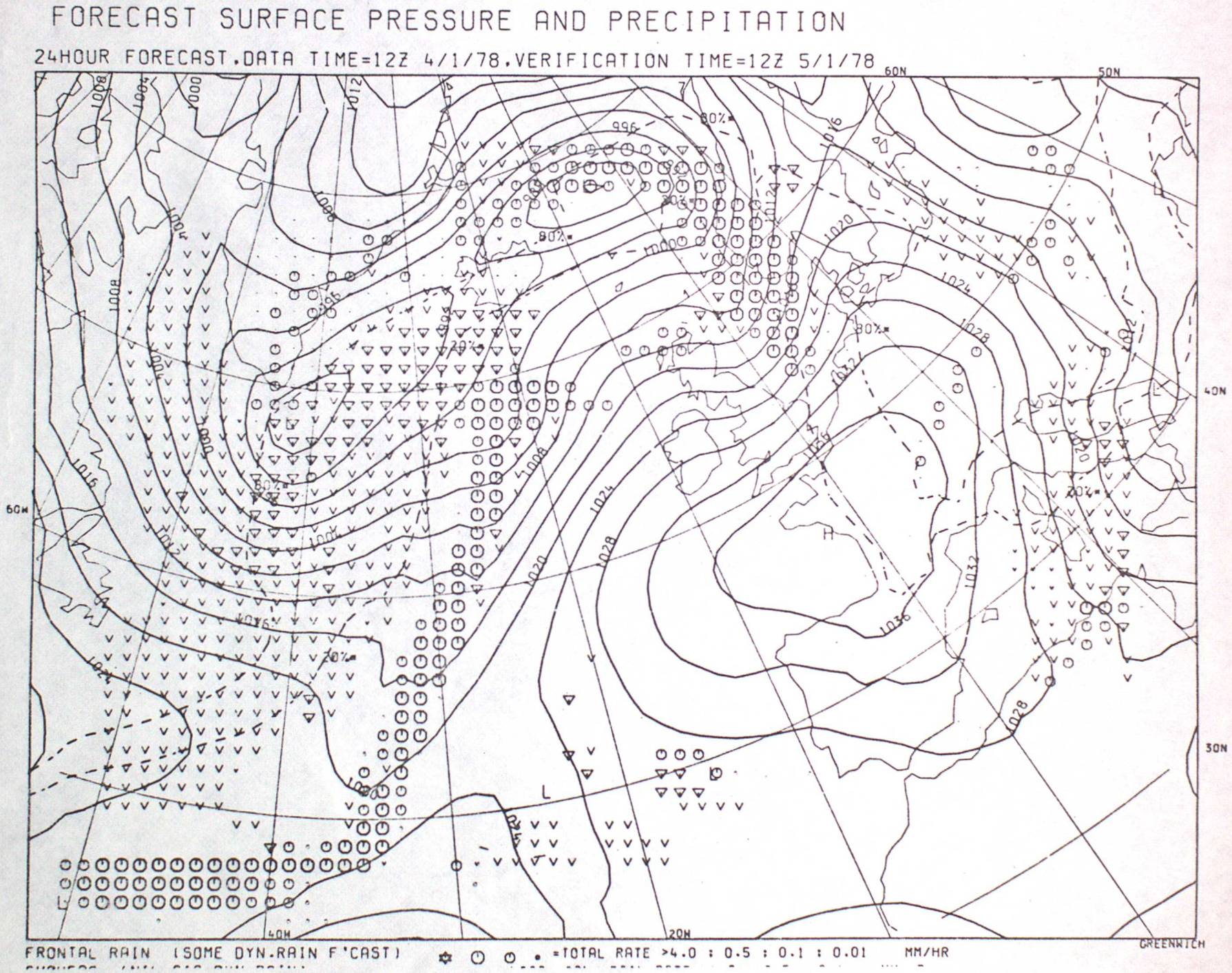


FIG.3. An example of a 24 hour rectangle forecast. (See attached sheet for key to symbols)

Fig.3. An example of a 24 hour rectangle forecast.

KEY:

Frontal Rain (some dynamic rain forecast)

= Total Rate >4.0; 0.5; 0.1; 0.0/MM/HR

Showers (nil significant dynamic rain)

= Local convective rate > 4.0; 0.5; 0.1MM/HR

Snow Key (for U.K.area only)

Dash lines give 20% and 80% probability of snow based on the forecast 1000-900mb thickness.